Introduction: Thinking with Algorithms: Cognition and Computation in the Work of N. Katherine Hayles

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> The microcomputer […] allows mathematics to be practiced as an experimental science. It has also affected how people have imaged themselves and their relation to the world (Hayles, 1991: 6).

In 2016, *Google*'s *Natural Language Understanding* research group began to train a deep neural network algorithm on a corpus of data comprising the literary works of 1000 deceased authors, from William Shakespeare to Daniel Defoe and from Virginia Woolf to Herman Melville.[1] The machine learning algorithm was reported by the scientists to have discovered the style of particular authors from their body of work, so that "given a sentence from a book and knowledge of the author's style and personality" the model could also "predict what the author is most likely to write next". [2] In fact, the algorithm had done what many neural network machine learning algorithms do: it had clustered the literature according to the patterns in the text as data, and then defined these clusters in terms of the *attributes* of the author's body of work. Once recognised and learned, these attributes became a means to identify the future attributes of as yet unknown texts. This apparently frivolous and innocuous experiment actually has immense significance for how people have imaged themselves and their relation to the world amid new computational forms. Unlike deductive forms of reasoning, where a rule or hypothesis is formulated and tested empirically, these algorithms are inductively generating potential attributes from the patterns within a corpus of data. Not only of epistemological significance, such processes of machine learning algorithms identifying clusters from data, generating attributes, and finding those attributes in the patterns of other people, are also shaping relations to the world, from Cambridge Analytica's attributes of voters to SKYNET's attributes of terrorist threat (Grothoff and Porup 2016).

The *Google* Natural Language experiments are but one example of how what N. Katherine Hayles has termed "computational regimes" are turning to literature[3] – and indeed other cultural media such as music and film – precisely in order to supply deep learning algorithms with a corpus of data from which they can refine their cognitive models of the world. As the Google computer scientists explain the motivation for their 1000 authors project, it is "an early step towards better understanding intent".[4] The algorithmic practices

that are pressing upon the politics and ethics of our times are geared toward a particular kind of question: given the attributes of a cluster within a corpus of data, what is the incipient future intent? This could be future voting intentions, the intent to commit fraud, the intent to buy life insurance, or the intent to stream a specific video. At the level of the technique what matters is not so much the content as the inferred future. So, teaching an algorithm to differentiate styles and sensibilities within literature – for example how one author's use of the line "who's there?" means something different to another author's use of the same line in another text – is actually also about teaching algorithms to make finite distinctions and to infer meanings in the future. Contemporary algorithms being used across domains, from credit card fraud to voter preference to counter terrorism, are being trained to understand future intent through the attributes of style and genre. In short, the conjoined histories of reading and learning in science and literature are finding new forms with the machine learning algorithms of the twenty-first century.

At this contemporary moment, when it might appear that science and literature, and humans and machines, are coevolving in novel and often troubling ways, the work of N. Katherine Hayles stands as compelling testament that these histories have never been separable. A literary theorist with a background in science, Hayles has consistently and imaginatively insisted upon a "technogenesis" of "reciprocal causality between human bodies and technics" (2012: 123). With technogenesis, humans and technologies coevolve so that the "interactions of language with code" bring about cognitive and neural changes in humans (2012: 10). Though I suspect that Hayles would not wish it to be said that she had anticipated, via her deep theorization of human and machine cognition, the unfolding computational phenomena of our times, I also note that this sense of extraordinary foresight is something which is rather commonly said of the men who theorise computational logics and societal transformation.[5] Similarly, though I do not think it likely that Hayles would wish to hear of a "Haylesian" approach to theorising contemporary computation, on all of the evidence this would be warranted and, again, it is commonplace to hear of the "Latourian". And so, I consider it to be of real significance that, 27 years ago, in the introduction to her edited work on literature and the science of chaos theory, Hayles foresees the elements of an algorithmic computational regime that had not yet fully emerged. When she notes that the computer allows mathematics "to be practiced as an experimental science", Hayles opens the way to understanding entangled and collaborative human and machine inferences that feel their way towards a solution (1991: 6). In this passage she describes someone sitting down at a computer "to model a dynamical non-linear system" where she "need not

proceed through the traditional mathematical method of theorem-proof" but can "set up a recursive program" (6). "With her own responses in a feedback loop with the computer, she develops an intuitive feeling for how the display and parameters interact", writes Hayles, describing the embodied interactions between the human neural system and the system of nonlinear differential equations (6). It is precisely such insight into the recursivity of human-computer relations, and the modifications this implies for traditional deductive methods, that is of crucial significance to understanding the computation of our times.

Over the period of the 27 years since Katherine Hayles wrote those lines, she describes a historical "arc" across three of her texts – *How We Became Posthuman* (1999), *Writing Machines* (2001), and *My Mother Was a Computer* (2005) – from the cybernetics of the mid-twentieth century to the present "versions of the posthuman as they continue to evolve in conjunction with intelligent machines" (2005: 2).[6] Yet, preceding this arc, the 1991 work does seem to anticipate the experimental and intuitive practices of the twenty-first century's machine learning algorithms, where designers sit before a model they have trained on a corpus of data. Today, the training of a convolutional neural network for image recognition, for example, involves many millions of parameters, certainly exceeding what the designer can meaningfully observe (Krizhevsky, Sutskever and Hinton, 2012). As Luciana Parisi captures it in her essay in this special issue, we are witnessing "a new mode of algorithmic processing" that "learns from data without following explicit programming" and "without abiding by the formal language of mathematics". Hayles' depiction of iterative and co-evolving interactions – observing the output and adjusting the probability weights in the model – nonetheless signals in 1991 the sense-making and meaning making collaborations between human and machine that will dramatically shape the world. It is these questions of thought and cognition, and how operations of thinking and cognition are distributed across human and technical agencies, that Hayles turns to in her two most recent books. In *How We Think* (2012), Hayles investigates the multiple forms of reading involved in engaging digital and print media, proposing that "machine reading might be a first pass toward making visible patterns that human reading could then interpret", opening new possibilities for cognition and for critical thought (2012: 29). In her *Unthought* (2017), Hayles extends her concept of cognition, challenging the human/nonhuman binary and offering "another distinction: cognizers versus noncognizers" in which "on one side are humans and all other biological life forms, as well as many technical systems" and "on the other, material processes and inanimate objects" (2017: 30). It is this recognition of the cognitive power of technical systems, and specifically their capacity to exercise choice and make decisions,

that has afforded Hayles' work such significance to contemporary debates. Yet, the cognitive power of technologies should be understood in its longer genesis across the analogue and digital forms of computation Hayles brings to our attention. Returning to the 1000 authors project, perhaps a Haylesian reading would urge caution with the idea that forms of machine reading are subsuming the human forms of deep reading of these authors. The human and the algorithm are co-evolving, yielding new modes of reading and cognition that do not readily map onto conventional notions of the human and the machine.

Thinking With Algorithms

This special issue of *Theory, Culture & Society* focuses on the literary theorist N. Katherine Hayles' oeuvre at the intersection of literature and computational science and technology. Each of the invited papers was presented at a workshop at Durham University in 2015, held with Hayles, and focused on her work in the context of contemporary debates on algorithms in society. The series of articles respond in different ways to the provocations of Hayles' work – engaging, challenging and extending the possibilities of her texts. In a direct sense, the articles signal the multiple manifestations of the computational regimes Hayles has mapped, from the algorithmic interactions of high frequency trading (Mackenzie) to the personalization of recommendation algorithms (Lury and Day). The multiple forms of Hayles's non-conscious cognition appear to us in different ways across the essays, with the apparently non-conscious human propensities that are considered not fully knowable to us becoming amenable to the differently non-conscious impulses of technical cognizers that generate clusters, sentiments and attributes. The collection is also intended to draw attention to what I see as a form of neglect in many contemporary accounts that have been caught up with the "digital", as for example in some variants of digital geographies, software studies, and data sociologies. The work of N. Katherine Hayles, over many decades, has opened the world of machinic and human reading and writing to thought and to literary practice. This is part of a longstanding body of work in the humanities, as well as in feminist and posthuman historical scholarship on science and technology (Haraway, 1991; Braidotti, 2013; Daston, 1988), that has not always received sufficient attention amid the contemporary desire to understand the digital, the virtual, or the cyber. To think with algorithms in these terms would also involve a thought that imagines human bodies as always already caught up in the algorithms thought to be governing them. It would mean that many of the questions animating current ethico-political debate on algorithmic accountability or automation anxiety would be rephrased to capture the historical durability

of concepts of perception, time, and decision. Do algorithms compute beyond the threshold of human perceptibility and consciousness? Can 'cognizing' and 'learning' digital devices reflect or engage the durational experience of time? Do digital forms of cognition radically transform workings of the human brain and what humans can perceive or decide? How do algorithms act upon other algorithms, and how might we understand their recursive learning from each other? What kind of sociality or associative life emerges from the human-machinic cognitive relations that we see with association rules and analytics?

In this introduction I draw out a set of themes from Hayles' work, identified as key animating ideas that give life to particular aspects of the contemporary debates on algorithmic computation and cognition. These themes are present across the different essays in the special issue and they are threads that run through the major contributions of Hayles' work across disciplines: human and technical cognitions; feedback loops and forms of reason; and ethics and futures. The special issue concludes with an interview with N. Katherine Hayles, in which she discusses her work on cognition and computation as it is formulated in her book *Unthought*, and responds to some of the questions arising from the essays in this issue.

"When we design technical cognitive systems, we are partially designing ourselves": human-algorithm interactions[7]

In a discussion of Stanislaw Lem's 1976 novella 'The Mask', Katherine Hayles details the partial and distributed nature of what we call human agency (2005: 172-3). "We are no longer the featherless biped that can think", she writes, but a "hybrid creature that enfolds within itself the rationality of the conscious mind and the coding operations of the machine" (2005: 192). Detailing the "machine within the human" and the "human within the machine", Hayles defines anew the problem of human agency in relation to the machine. In place of a long-held sense of human agents as rational beings exercising free will in the world, Hayles shows how the sense of self and world is bound up with underlying programmes so that "coding technology becomes central to understanding the human condition" (2005: 192). Understood in this way, thinking with algorithms could only ever be an entangled and collaborative venture in which analogue and digital forms of computation and cognition dwell together. This hybrid and collaborative mode of cognition is further elaborated in *Unthought*, where Hayles develops the concept of a "cognitive assemblage" to depict the "arrangement of systems, subsystems, and individual actors through which information flows, effecting

transformations through the interpretative activities of cognizers operating upon the flows" (2017: 118). Here, the technical cognitive system is composed of multiple elements, humans and algorithms among them, each of these elements interconnected so that "the cognitive decisions of each affect the others" (2017: 118).

From the algorithmic infrastructures of smart cities to the use of autonomous weapons in contemporary warfare, Hayles' insights remind us that the design of technical cognitive capacities also necessarily involves a redesignation of what it means to be human. "Autonomous drones and drone swarms would operate with different distributions of choices, interpretations, and decisions", she writes, but they too will necessarily "participate in a complex assemblage involving human and technical cognizers")2017: 136). Given this complex assemblage, with its different distributions of decision, what is at stake for the way one studies algorithms? As Celia Lury and Sophie Day discuss in their study of recommendation algorithms in this special issue, the algorithms function as a "composite of algorithmic and human reasoning". And yet, the dividuated human subjects that are generated through the chains of "like" relations in recommendation systems, as they describe, run counter to traditional conventions of a unified subject, instead embodying algorithmic processes "such that one is always more and less than one". The subject of the recommendation algorithm, then, dwells among human and technical cognizers so that the distribution of decisions does not map directly to the "one" of the liberal human subject. In her analysis of Shelly Jackson's electronic hypertext, *Patchwork Girl*, Katherine Hayles describes how the "unified subject is thus broken apart and reassembled as a multiplicity" via electronic media that distribute coding and decoding "between the writer, computer and user" (2005: 151). This redistribution of the text as a "flickering signifier" is arguably not confined to the spaces of story writing, but proliferates also in the kinds of recommendation algorithms depicted by Lury and Day, where subjectivities are enacted in what Hayles calls "flexible and mutating ways" (2005: 154).

As Luciana Parisi suggests in this special issue, Hayles' work "offers a re-reading of the epistemological distinction between human and non-human cognition" and, specifically, a re-reading of how non-human cognizers interact with other human and non-human cognitive agents. The effects of cognition, as distinct from thought, have been manifest particularly in systems where algorithms interact with, and learn from, other algorithms in order to enact decisions. Indeed, Hayles devotes one chapter of her book *Unthought* to the study of high-frequency trading (HFT) in financial derivatives markets. In the context of vast increases in

processor speed, computer memory, and the use of fibre optic cables, Hayles identifies a "temporal gap between human and technical cognition" that she suggests creates "a realm of autonomy for technical agency" (2017: 142). What might take place in this space of relative technical autonomy? In his essay on HFT in this special issue, Donald Mackenzie is interested in what he calls, following Erving Goffman, the "interaction order" of algorithms. "Among the things an algorithm does in automated trading", writes Mackenzie, is to have "material effects on the behaviour of other algorithms". Detailing how the object of the "order book" emerges, Mackenzie describes the "human traders" who, like the algorithms with whom they work, "simultaneously observe and construct the object of their attention". In this way, the temporal gap Hayles identifies is manifest in the technologies of "spoofing" and "queuing" Mackenzie recounts in his study. Indeed, Hayles engages with Ann-Christina Lange's work on HFT in order to emphasize how "algorithms are constantly interacting with other algorithms, generating a complex ecology that, Lange suggests, can be understood as swarm behaviour" (2017: 163).[8] In the financial practice of HFT, then, the cognitive assemblage enrols human and algorithmic interactions that take place across different temporal registers. Such readings, as one sees across work by Hayles, Lange, and Mackenzie, substantially complicate the widespread claims to a "speeding up" of the world amid the dominance of algorithms over human decisions. Similarly, the very notion of a liberal human subject is reframed so that, as Michael Dieter argues in his essay on chrono-design and user experience, "conceptions of a fully-informed, self deliberative actor become complicated" in algorithmic systems of cognition. What it means to action a trade, to design an interface, to queue or to spoof, is transformed in and through the composite cognitions of humans with algorithms, and algorithms with other algorithms.

"Recursive feedback loops cycling between different levels of coding": algorithmic forms of reason[9]

Reflecting on Norbert Wiener's mid-twentieth century concerns for the cybernetic paradigm, Katherine Hayles notes that:

> Half a century later, we can see with the benefit of hindsight in what ways the cybernetic paradigm was both prophetic and misguided. It was correct in anticipating that modes of communication between humans, non-human life-forms, and machines would become increasingly critical to the future of the planet; it was wrong in thinking that feedback mechanisms were the key to controlling this future (Hayles, 2017: 202).

Alongside the distribution of agency and cognition, then, the recursivity of interactions have exceeded the capacity of traditional notions of control. With the recursive feedback mechanism – a technic present across Hayles' oeuvre – Hayles signals the limit points of formal mathematical and computational systems and the possibilities of novel forms of reason more attuned to the "incomputable, the undecidable, and the unknowable" (2017: 202). Understood in this way, the feedback loop that was so central to cybernetic forms of reason and control becomes a recursive and iterative logic that exceeds notions of control.[10] As contemporary machine learning algorithms deploy back propagation to train multilayer architectures, the notion of feeding back has become a crucial feature of unsupervised learning that precisely no longer requires control. In her essay, Parisi extends what she describes as Katherine Hayles' identification of a fundamental problem in our present, that is the tension between logics of automation and reason. Parisi identifies a "shift in computational models of logical reasoning" from enlightenment forms of "deductive truths applied to small data" to contemporary computational forms of the "inductive retrieval and recombination of infinite data volumes". Extending and developing Hayles' account of the computational regime, Parisi draws out a key aspect of the forms of reason advancing with machine learning. Similarly, Lury and Day propose that personalization via algorithm is not "a slide from one to many and back again" but instead a form of enumeration that is conducted through "forms of de- and re-aggregation" and "recursive induction in types or classes".

Such elaboration of the precise forms of reason advanced with machine learning algorithms is significant because it rather fundamentally challenges causal accounts of algorithmic actions upon the world. In place of an account of algorithms where the effects of their actions can be located in their origins or source codes, it becomes possible to give an account of algorithms as generating, and generated by, the relations between input data and their outputs. As Parisi puts the problem, "machine learning is the inverse of programming: the question is not to deduce the output for a given algorithm, but rather to find the algorithm that produces this output". In contrast to visions of the algorithm as a linear series of programmable steps, this abductive form of reason marks a generative process of the discovery of structure within large data sets.

Rather as Hayles' 1991 account of computation envisaged a regime that "allows mathematics to be practiced as an experimental science", then, the inductive or abductive

logics of machine learning experiment with outputs, adjusting probability weights in order to optimize the algorithm. Where Tobias Matzner suggests in his essay, contra Parisi, that the "stability of the world" is a "precondition of algorithm design", the experimental design of machine learning algorithms seems precisely to profit from instability and uncertainty because these conditions yield data to the corpus for learning. Michael Dieter's close study of the practice of user experience design, for example, observes processes of "accelerated pattern recognition, the synthesis of sensory inputs, and the capacity to draw inferences" in the algorithmic experiments for optimization. Donald Mackenzie's essay similarly describes financial traders he interviewed as "experimenting with artificial intelligence machine learning techniques" such as support vector machines to distinguish "real from spoof orders" in more sophisticated ways. Again, the machine learning methods required to define similarities and differences – such as the support vector machines Mackenzie observes – inductively generate their similarity measures from the attributes of the data they are exposed to (Alpaydin, 2016: 116; Mackenzie, 2017: 73).

As Katherine Hayles notes in the epilogue to *My Mother was a Computer*, the cyberneticians of the mid twentieth century were the architects of "feedback loops connecting human and machine" and yet they had "not quite grasped" that "recursivity could become a spiral rather than a circle" (2005: 241). In short, the architects of the feedback loop as computational logic did not quite foresee its capacity to generate emergent behaviours that would spiral beyond a paradigm of control and form the parameters of modes of reason attuned to uncertainty and contingency. Perhaps our current moment, with the encroachment of algorithms on democratic elections, referenda, and the judicial system, is witnessing what Hayles describes as "the uncertainties, potentialities, and dangers" of the algorithmic regime of computation (2005: 242). It is to these latent potentialities and dangers that I now turn.

"Ethics Cannot Be Plastered on as an Afterthought": algorithms and positive futures[11]

In an interview published in this special issue, N. Katherine Hayles reflects on her own contribution to the formulation of ethical responses to the penetration of algorithmic decisions into so many aspects of contemporary life, saying that she does not consider herself to be an "ethicist". The reading of her work that I offer here, however, considers that she has a profound sense of ethics as an orientation to oneself and to the world, and of the ethical and moral difficulties of being human. Consider, for example, her account of

posthuman embodiment, where she discusses whether, with the “rapid development of neural nets”, there could be a fundamental challenge to the “ethical imperative that humans keep control” (1999: 288). Hayles contrasts the “vision of the human in which conscious agency is the essence of human identity” with the posthuman view that “conscious agency has never been in control” (1999: 288). Citing feminist scholars of science such as Donna Haraway and Evelyn Fox Keller, Hayles suggests that the posthuman can offer another kind of account in which “distributed cognition replaces autonomous will; embodiment replaces a body seen as a support system for the mind; and a dynamic partnership between humans and intelligent machines replaces the liberal humanist subject’s manifest destiny to dominate and control nature” (1999: 288).

Twenty years on from Hayles’ mapping of the potentiality of the posthuman to decentre human conscious agency, the dominant societal and scholarly accounts of ethical response to algorithms remains wedded to the control functions of the liberal humanist subject (O’Neil, 2016). It is perhaps more important than ever that Hayles’ call for embodied accounts of dynamic partnerships are brought into conversations on drone warfare, autonomous weapons, and robot futures, where the capacity for human control and mastery of the algorithms has too often become the focus of ethico-politics.[12] Indeed, in *Unthought* Hayles urges us to consider the potentiality of non-conscious forms of cognition to extend new opportunities for human thought and critique. Whilst she never loses sight of the ethical effects of the assemblages of algorithmic warfare, she nonetheless seeks to “move from thinking about the individual” as site of responsibility and free will, toward thinking about “the consequences of the actions the assemblage as a whole performs” (2017: 37). For Hayles, this mode of ethics means that “effective ethical intervention has to be intrinsic to the operation of the system itself” so that the sites of “inflection points” can be located within a cognitive assemblage (2017: 204). What does this mean for those who research the actions of algorithms in the world? It means becoming “knowledgeable about how the interpenetrations of human and technical cognitions work as specific sites”, devoting methodological time to understanding computational regimes up close and in their operations.

The essays assembled in this special issue may be read as engagements with this invocation to understand a computational regime in detail and to identify the inflection points where intervention might be possible. Such inflection points take multiple forms. In his discussion of the trapping of “technical delays and waiting times within tolerable limits”, for

example, Michael Dieter engages the specific and distinct micro temporalities of information. Donald Mackenzie's close study of HFT regimes exposes that "it is human beings, not algorithms, that are angered by perceived queue jumping" and it is "humans, not algorithms, that are prosecuted for spoofing". Here the potential inflection points reside in the moments where the different temporalities and affective registers – delays, emotions of anger, tolerable thresholds, fears of prosecution – are juxtaposed or drawn together in tension with one another. The point is that engaging the technical cognitions in detail can yield a different way of relating to the system ethically and politically. As Adrian Mackenzie has argued in his compelling account of the archaeology of machine learning algorithms, understanding how a specific algorithm such as a random forest "orders differences" could provide a means to "change how we relate to" one of the material instantiations of such algorithms in the world, such as in border and immigration controls (2017: 11).

Of course, for Hayles the reading of the close detail of a computational regime draws much of its resource from the humanities and, particularly, from the "specific dynamics" that "novels enact that are not already present" (2017: 198). Among the specific dynamics of novels, Hayles notes that "novels explore ethical issues in specific and concrete terms" (2017: 200). The decision enacted within the novel's form is already freighted with political, ethical, technical, and affective weights of meaning. Hayles' account of the ethicality of the novel's form can serve as a reminder that the decisions of the computational regime are also already weighted with the biases, probabilities, and discriminations contained within algorithms. In her book *Writing Machines*, Hayles experiments with "what the book can be in the digitial age" (2002: 9). Writing in the third person, and under the name "Kaye" (related to Hayles, but "not the same"), Hayles enacts the displaced authorship and partial perspective that feels familiar to us from literature, but also increasingly familiar as a function of the kinds of personalization algorithms studied by Lury and Day – not quite the one of I, always something less and more than this. Experimenting with the form of writing and the novel, Hayles vividly conjures the ethical difficulties of the human protagonist who finds herself enmeshed within technical cognitive systems and yet also the subject of an "asymmetric distribution of ethical responsibility in whether actions are finally taken" (2017: 136). As the essays of this special issue elucidate, this is not primarily a question of resolution, nor of resolving or ethically modifying the distribution of responsibility. Instead, as Hayles' work has mapped over decades, it is a question of how the science that "underwrites the Regime of Computation" can yield the potential to "deepen our understanding of what it means to be in the world rather than apart from it" (2005: 242).

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[1] For the Google research team's account of the development of their algorithms see https://research.googleblog.com/2016/02/on-personalities-of-dead-authors.html Last accessed January 2018.

[2] http://www.wired.co.uk/article/google-author-create-artificial-intelligence Last accessed February 2018.

[3] Katherine Hayles' notion of the "regime of computation" emphasizes the performative relations between computation (code or "the language in which computation is carried out") and preexisting "models for understanding truth statements", whether literature or metaphysics (2005: 17). Significantly, this means that "computation is not limited to digital manipulations" and can "take place in a variety of milieu and with almost any kind of material substrate" (p.17). Computational regimes are thus situated in places and spaces, and they involve material and corporeal relations.

[4] Anthony Cuthbertson, "Google's AI Predicts the Next Sentence of Dead Authors", *Newsweek*, February 29, 2016.

[5] See, for example, Bruno Latour (1999); Bernard Stiegler (1998); Gilbert Simondon (2001).

[6] My identification of a period of 27 years should not be read as the period of the influence of N. Katherine Hayles' work, of course, which has extended over many decades. Rather, the 1991 text pre-dates the arc of the work Hayles herself describes, and thus serves to illustrate the presence of extraordinarily prescient themes pre-dating the major series of books.

[7] For Hayles there is a great deal at stake in recognizing how human cognition "enmeshes with technical systems" so that "when we design technical cognitive systems, we are partially designing ourselves" (2017: 141). She argues that it is only through reassessing "humbler perceptions of human roles in cognitive assemblages" that society might "collectively decide to what extent technical autonomy should and will become intrinsic to human complex systems" (141).

[8] Hayles cites Ann-Christina Lange's (2015) paper on swarm theory and HFT. See also Lange (2016) on the ethnographic study of practices of HFT.

[9] Discussing the future of posthuman subjectivity through four novels, Hayles suggests that "the subjects of these texts achieve consciousness through recursive feedback loops cycling between different levels of coding" (1999: 279). If posthuman subjectivity is rewritten through layered coding structures, she proposes, then different "models of signification" are required to account for the "distinctive feature of neurolinguistic and computer language structure" (p.279).

[10] The idea that "recursion was central to cognition", Hayles explains, extended through "much improved imaging technologies, micro-electrode studies, and other contemporary research practices" (2017: 47). On recursion and algorithmic logics, see also Totaro and Ninno (2014); and for detailed engagement with feedback loops and the algorithm see Halpern (2015).

[11] "Ethics cannot be plastered on as an afterthought", writes Hayles of algorithmic systems that lead to sometimes catastrophic effects, whether financial crisis or drone strike, for example (2017: 204). Her notion of an ethical intervention is situated in what she has described as "close reading", so that the computational regime is studied in situated detail.

[12] For embodied accounts of the operations of drone algorithms and autonomous weapons systems see Wilcox (2017) and Suchman and Weber (2016).